Development of a Suite of Benchmark Tests for Oceanic and Coastal Wave Models

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LONG-TERM GOALS

The primary goal of this project is to develop, on the basis of the present SWAN benchmark suite, a first version of a generic community suite covering both oceanic and coastal conditions. This will provide the basis for a suite that will qualitatively and quantitatively compare the computational results of any wave model of the spectral type with objective data from theoretical sources (analytical solutions) and empirical sources (laboratory and field observations). The suite will be generic in the sense that a) a diversity of wave models can be evaluated against such data and that b) an internationally agreed-upon fixed set of tests is used so that the score of different models can be intercompared. The suite is a community tool and will be provided to the international community to enable operational institutes and researchers around the world to test their wave models in a joint framework with common data and common score definitions.

The SWAN benchmark suite which is mentioned above has been developed over the last few years as a steady-state benchmark suite (Ris et al., 1999; WL | Delft Hydraulics, 2000) to assist operational institutions and researchers to evaluate the scientific and numerical performance of (new versions of) the SWAN coastal wave model (Booij et al., 1999). In this suite the model performance is evaluated by comparing the computational results with data in academic cases (analytical solutions and laboratory data) and in real field cases (sandy coasts including the surf zone).

SCIENTIFIC OBJECTIVES

The main objective is a generic system that can evaluate numerical wave models to support the development of the best possible wave forecasting (and hindcasting). This requires the evaluation of a variety of wave models in a variety of conditions ranging from validation tests (academic) to verification tests (real field cases) and from large-scale (oceanic) conditions to small-scale (coastal) conditions. With the proposed development of a community suite with an internationally agreed-upon set of *generic tests cases* and *high quality data*, this evaluation can be carried out efficiently for any wave model of the spectral type. The tests will be standarised such that the score of one model can be compared to that of

another model. This development avoids the typically required *ad hoc* efforts involving extensive testing of two or more (versions of) models against observational data.

APPROACH

To facilitate the evaluation of a large diversity of wave models of the spectral type in oceanic and coastal applications, Delft Hydraulics will make the currently available suite of steady-state benchmark tests of the SWAN model generic and it will extend it to unsteady-state (oceanic) conditions. It will be made generic by providing fixed formats and example-converted input files. It will be extended with one available steady-state US field data set (i.e. observations of DUCK-DELILAH) and by adding up to ten unsteady-state data sets (primarily from US sources). The selection of the tests will be made in consultation with the WISE group and subject to the approval of ONR representatives.

Within the project the steady-state (coastal) model STWAVE (see e.g. Smith et al., 1999) will be added to the steady-state benchmark suite and the unsteady-state (oceanic) model WAVEWATCH-III (Tolman, 1991, 1998) will be added to the unsteady-state benchmark suite. The two versions of the suite (steady- and unsteady-state) will be fixed in the sense that no options will be available to the user so as to prevent deviations from the definitions of the benchmark scores. On the other hand, the code will be open enough that new or modified test cases and new or modified statistical scores are readily added (minimum flexibility for the operational use and maximum flexibility for continued development). Executing the benchmark suite for a specific wave model will only require a conversion of all I/O files for that model. Two such I/O conversions will be provided: one steady-state (STWAVE) plus one unsteady-state (WAVEWATCH-III).

The comparison of the computational results with observations in this suite will be qualitative through the use of graphics and it will be quantitative by using statistical measures. The wave parameters to be considered are the significant wave height, a mean wave period and the mean wave direction (if available in the observations). The statistical measures are the bias, the rms error, the scatter index (except for directions), the operational performance index and the model performance index (if relevant). Brief documentation will be provided in the form of limited guidelines for experienced users. This will consist of: a) implementation and user manual, b) a description of the suite of bench mark tests and c) reporting protocol.

The benchmark tests (steady-state and unsteady-state) will be executed and the results will be reported.

The work will be carried out in close consultation with several leading model developers and users. Active support, assistance and advice on the project is provided by L. Holthuijsen, N. Booij and H. Tolman.

WORK COMPLETED

General:

1. The goal, the tests, the required data sets (bathymetry, wind, waves etc.), the scores and the tasks of the test bed (both the steady and unsteady-state version) have been discussed extensively with several scientists, leading model developers and users at the AWPP-meeting (April 2000, Delft, the Netherlands). The test bed group (L. Vincent, H. Tolman, V. Cardone, H. Graber, R. Jensen, D.

Resio, T. Herbers, B. O'Reilly, L. Holthuijsen and N. Booij) agreed upon that the following test cases will be included in the unsteady-state test bed:

***Extra-Tropical Storms*:**

- SWADE IOP-1 (Cardone et al., 1996)
- The Halloween Northeaster (Cardone et al., 1996)
- Two storms of 1 month each during the NSCAT time period and northern winter.

***Hurricanes*:**

- Luis (Atlantic Ocean non-landfall)
- Georges (Gulf of Mexico landfall)
- Felix *or* Gordon (Atlantic Ocean non-landfall)
- Fran (Atlantic Ocean landfall).

2. Preliminary results of the steady-state test bed have been presented at the WISE 2000 meeting (June 2000, Reykjavik, Iceland).

3. Since the start of the project (March 1, 2000), discussions on the test bed project are frequently being held with L. Holthuijsen and N. Booij.

Steady-state test bed:

1. The present SWAN-test bed has been extended with steady-state field observations of DUCK-DELILAH.

2. The present SWAN-test bed has been modified and updated such that only *high quality data* and *generic test cases* remain within the new steady-state test bed. Moreover, the definition of the format of output files, graphics and statistics, the protocol and all other documents has been finalised.

3. The steady state wave model STWAVE has been added to the steady-state test bed. To that end: a) new directories for STWAVE have been added, b) an I/O conversion file for STWAVE has been developed, c) new script files (i.e. files that control the pre- and postprocessing and the STWAVE computations) have been made and d) all input files for STWAVE have been generated.

4. The post-processing program for the statistical analysis in the SWAN-test bed has been modified and updated such that the scores can be determined for any wave models within the steady state test bed.

Unsteady-state test bed:

The third-generation wave model WAVEWATCH-III has successfully been installed on our Unix machines and is presently operational for testing purposes.

RESULTS

Preliminary results of the (steady-state) benchmark tests for the STWAVE model have been presented at the WISE 2000 meting. An example of one of the test cases within the steady state test bed is the

Haringvliet estuary. As an example the case description is given below according to the *reporting protocol*. In addition, preliminary results in terms of computed wave spectra of SWAN and STWAVE are also shown.

Case description (example):

F31 Haringvliet estuary (the Netherlands)

Purpose

To test wave propagation and the formulations of the physical processes, in particular that of triads and the regeneration of waves by local wind effects, the wave model is applied in the complex field case of the Haringvliet Estuary (the Netherlands).

Situation

The Haringvliet is a relatively shallow branch of the Rhine estuary in the south-west of the Netherlands, separated from this estuary by sluices (Andorka Gal, 1995). The water depth is 4 to 6 m and the surface area is about 10 km × 10 km (Figure 1). The bay is partly protected from the southern North Sea by a shoal ("Hinderplaat") extending half across the bay entrance. The waves approach the estuary from deep water and break over the shoal with a reduction of wave energy. Deep inside the branch, the local wind regenerates the waves (which is evident as a high-frequency peak in the observed spectra). A constant and homogeneous wind speed U_{10} is considered for each test case. Currents are assumed to be absent.

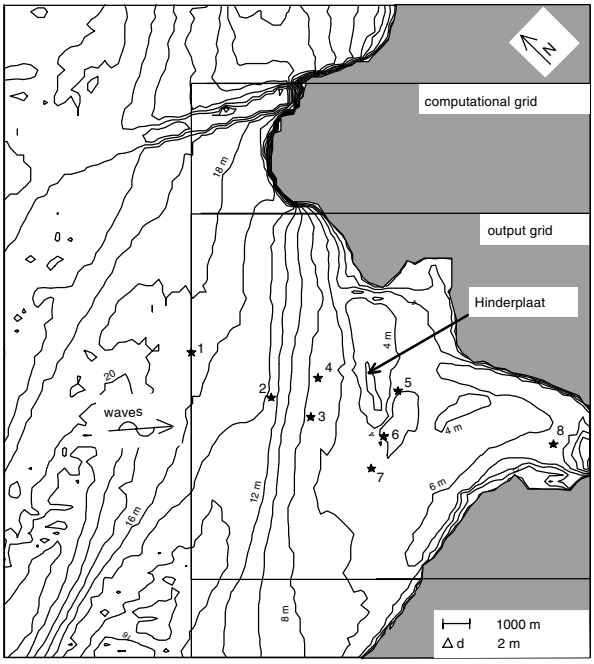

Figure 1 Bathymetry of the Haringvliet estuary (the Netherlands) with the locations of the eight observation stations.

For each case the relevant physical parameters are shown in Table 1. These cases were selected because (a) the wind speed and the wind direction were fairly constant, (b) the waves

were fairly high (for the observation period of 13 weeks), (c) the water level was sufficiently low to see the generation of a significant secondary peak in the spectra near the shoal, but not so low that the shoal would be dry.

Comparison

At eight locations observations are available. Comparison is being made with the wave spectra and integral spectral parameters H_s and T_{m01} as produced by the model.

Table 1 Physical parameters for all cases within group F31. Wind speed in U_{10} and direction according to nautical convention. Time in UTC.

Case nr.	*Date/Time [dd-mm-yy/hh:mm]*	*Waterlevel [m]*	*Wind (U_{10}) [m/s]*	*Direction [^{0}]*
01	*14-10-1982 / 21.00 hrs*	*+.30*	*17*	*330*
02	*14-10-1982 / 22.00 hrs*	*+.90*	*12*	*300*
03	*14-10-1982 / 23.00 hrs*	*+1.70*	*14*	*300*
04	*14-10-1982 / 24.00 hrs*	*+2.10*	*15*	*300*

References

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Dingemans, M.W., 1983: Verification of numerical wave propagation models with field measurements; CREDIZ verification Haringvliet, Rep. W488, Part 1b, Delft Hydraulics, Delft, The Netherlands

Acknowledgements

Data courtesy of J.H. Andorka Gal and J.G. de Ronde of the Dutch Ministry of Public Works and Coastal Management (RIKZ), Den Haag, the Netherlands.

(Preliminary) results of test case:

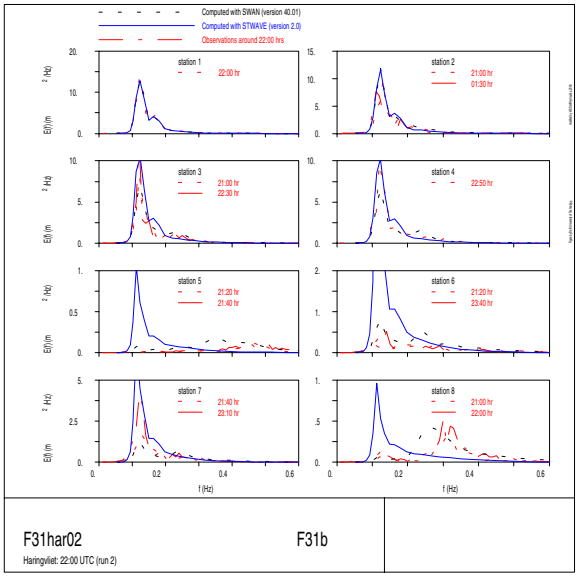

Figure 2 Computed and observed wave spectra at the eight stations in the Haringvliet estuary for test case F31HAR02.

IMPACT/APPLICATIONS

The development of a generic *community suite of benchmark tests* (agreed upon by leading model developers) for spectral wave models will promote the search for the best spectral wave model and the continued improvement of wave models. It provides a necessary component to enable researchers and operational institutes to evaluate the quality of new (versions of) wave models. This development agrees well with the current policy of ONR to promote the development of a *community wave model* as a common frame of reference for all related ONR projects. Results of related ONR-funded research projects, as and when implemented in wave models, are readily assessed with the proposed benchmark suite.

TRANSITIONS

The proposed generic community benchmark suites with all their data and documentation will be freely and unconditionally available (except for proper referencing to ONR funding and to the sources of information) to active members of the WISE group on CD-ROM (with a maximum of 50 copies to be provided for distribution by ONR). The US Navy and the US Army are active WISE members. Industrial counterparts are welcome to use the benchmark suite free of charge to the extent that they are active WISE members. If an institute is not an active WISE member, the suite is available on CD-ROM at nominal costs from Delft Hydraulics for a period of two years after the termination of the project.

RELATED PROJECTS

Listed below are various projects that are related to the present test bed project:

1. U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory: *Virtual Test Bed.*

2. Oceanweather Inc.: *Virtual Test Bed for Evaluating Wave Prediction Technology.*

3. Delft University of Technology: *The continued development of the third-generation shallow water wave model SWAN.*

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Tolman, H. L., 1998: A new global wave forecast system at NCEP. *Ocean Wave Measurements and Analysis*, B.L. Edge and J.M. Helmsley Eds., ASCE, 777-786.

WL | Delft Hydraulics, 2000: Suite of bench mark tests for the shallow water wave model SWAN, SWAN Cycle 2, Version 40.01 and updates. Report H3528, Delft, The Netherlands.

PUBLICATIONS

Oral presentation of preliminary results art the WISE 2000 meeting in Reykjavik, Iceland, June, 2000.